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The Upper-Layer Circulation of the Japan/East Sea: Historical Data Analysis

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LONG-TERM GOAL

The circulation of the Japan/East Sea is characterized by significant temporal and spatial variability due to several factors, including seasonal fluctuations in the warm inflow through Tsushima Strait, branching of the Tsushima Warm Current downstream of the strait, and the formation of mesoscale eddies along these branches. The long-range objective of the Japan Sea study is to understand the dynamical processes that govern this variability.

OBJECTIVES

Our objectives for the Japan Sea work were to:

1. Describe the synoptic three-dimensional structure of the branching of the Tsushima Warm Current and its seasonal variability.

2. Describe the spatio-temporal modes of variability in dynamic height and determine the primary sources of this variability.

3. Provide a better description of the origin of the Tsushima Warm Current in the East China Sea and seasonal variability in its T-S characteristics.

APPROACH

We used the very large AXBT data set from NAVOCEANO to investigate a) the structure and distribution of intrathermocline eddies and b) the seasonal variability in the three-dimensional, synoptic temperature structure and circulation in the East China, southern Yellow and southeastern Japan/East Seas in the upper 400 m. Previously, we converted the vast store of XBT data to dynamic height following the methods of Lagerloef [1994] to address Objective 2), but found that the error estimates were not random scatter, as hoped and as was the result in the Gulf of Alaska (where Lagerloef's study was conducted), but biased due to the profound effect salinity has on density structure in the Japan/East Sea. Therefore, we decided to focus more on the unique AXBT data set provided through NAVOCEANO and investigate the synoptic temperature structure and its variability.

TASKS COMPLETED

A study of intrathermocline eddies was completed and the results were published in the *Journal of Physical Oceanography* [Gordon, et al., 2002]. A second study of the temperature structure and circulation in the East China Sea, Yellow Sea and southern Japan/East Sea was completed and a

manuscript has been accepted (with minor revisions) for publication in *Deep-Sea Research* [Furey and Bower, 2003.].

RESULTS

An inventory of intra-thermocline eddies (ITE) has been made in the Japan Sea from six air-deployed XBT surveys from 1992 through 1995. The eddies, characterized in the XBT data by homogenous cores of greater than 100 meter thickness and mean temperatures of less than 12°C, have also been observed in other data to have a positive oxygen anomaly and negative salinity anomaly compared to surrounding thermocline water. The ITE properties indicate winter formation within the Japan Sea polar front, and subsequent subduction under the thermocline to the south. The AXBT surveys show two distinct ITE temperature groupings, one group having temperatures between 10° and 12°C, and the second (less common) around 7°C (Figure 1). The seasonally-repeated synoptic AXBT surveys allow us to see possible formation and follow the movement and water mass modification of the individual ITEs. The AXBT surveys indicate formation can occur in both winter and spring, with complete subduction taking less than three months. The core temperatures of the ITEs can be directly linked to surface temperature at the formation site, and the ITEs appear to translate 1.1 ± 0.4 cm/sec to the south-southwest after formation. These observations confirm the working hypothesis of ITE formation along the polar front.

We recently completed a study detailing the temperature structure and circulation of the East China, southern Yellow, and southeastern Japan/East Seas from AXBT data. The main focus of the paper is on four unique AXBT surveys that provide high-resolution coverage of these regions, providing the first synoptic view of quasi-seasonal (September, February, and May) surface to 400-meter temperature structure for this region. Over the entire region, we focus on mixed layer depth dynamics and temperature front structure at the surface, sub-mixed layer (60 meters) (Figure 2), and deep (100 meters) levels. Surface temperature structure is indicative of deeper temperature structure only in winter, when strong monsoonal winds mix the stratified water column often to the bottom (see red dashed line of Figure 2), and spring, before surface heating re-stratifies the water column. The two September surveys illuminate the possible differences in temperature structure. In 1992, the eastern Kuroshio temperature front (Kuroshio Front) is far on-shelf of its usual position between the 200-meter isobath and the mean Kuroshio path [Isobe, 1999a,b], blocking formation of eddies north of Taiwan, and branching into the Tsushima Strait. In 1993, the September Kuroshio Front is found off-shelf of its winter and spring position, and eddies have formed north of Taiwan, bringing cooler deep Kuroshio water onto the shelf [Tang, et al., 2000]. Despite the 1992 Kuroshio Front anomaly, subsurface temperature fronts through the Tsushima Strait exhibit a seasonal pattern that is consistent with SST fronts [Hickox, et al., 2000], where a front develops southeast of Cheju Island in both summers, and migrates north of Cheju Island in winter and spring. Possible downstream affect of the onshore position of the Kuroshio Front may be the off-shelf direction of the front through the western channel of the Tsushima Strait (Figure 2a), whereas in 1993, the September fronts in the eastern and western strait channels followed the Honshu coast once entering the Japan/East Sea (Figure 2d).

In addition to the regional results, we also focus on inflow and outflow of the Tsushima Strait and, using seven other AXBT surveys that cover the Tsushima Strait outflow region in the JES, we describe branching structure of the Tsushima Warm Current for the years 1992-1995. The East Korean Cold Current can be seen in summer only, reaching back into the western strait as far as the southern end of Tsushima Island. There is evidence of previously undocumented cold water entering the strait from the southwest, appearing to originate from upwelled water near the entrance of the strait. Branching patterns are not seasonally dependant, and fall into three categories: a) one front following the Honshu coast, b) two fronts splitting, one following the Honshu coast, and one following the East Korean

Coast (the East Korean Warm Current), and c) similar to b), but with the East Korean Warm Current appearing displaced to the east.

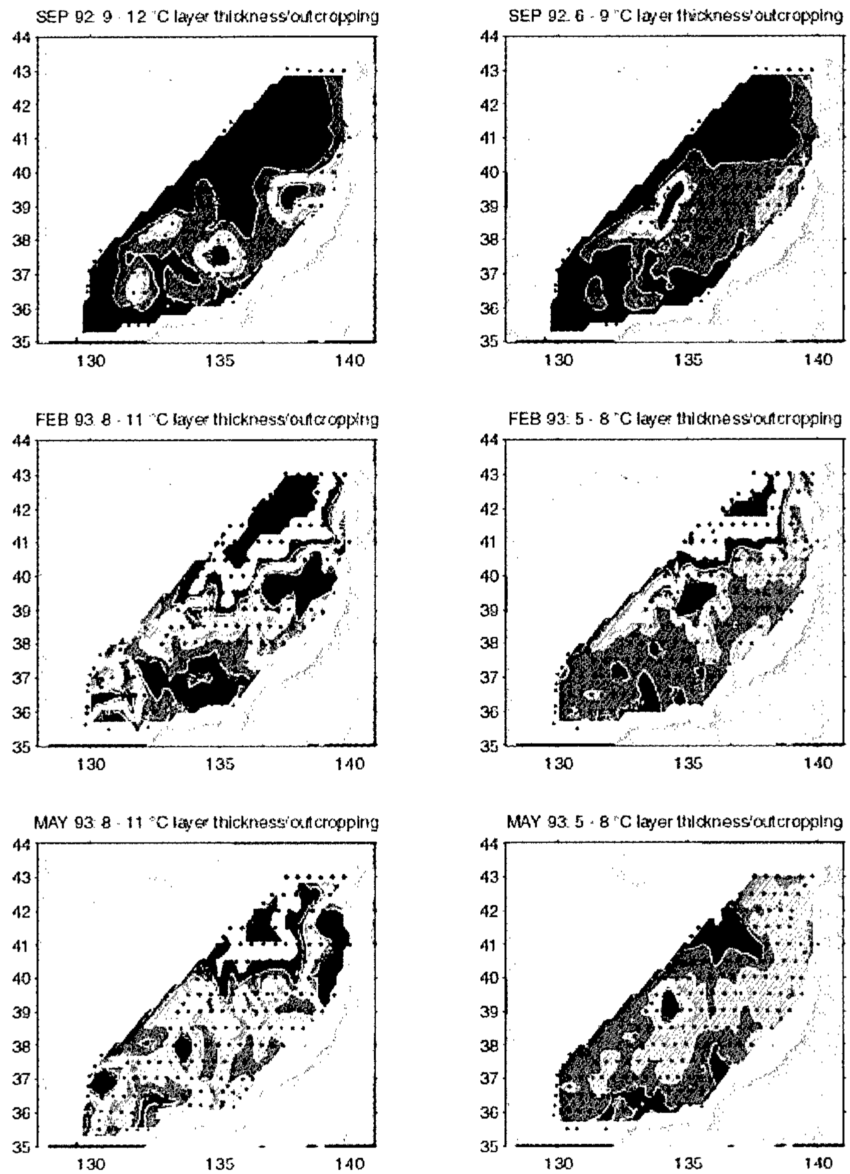

Figure 1: Thickness maps from three example AXBT surveys, from September 1992 to May 1993. Each survey has two panels, depicting the thicknesses (in meters) of the 'warm' and 'cold' Intra-Thermocline Eddy (ITE) layers. The station locations are designated by solid or open dots. If a layer is submerged, then the station marker is designated by a black dot. If the upper temperature of the layer has outcropped, then the station is marked with an open circle. For example, in September 1992, no outcropping occurs, and all data represent the layer thickness. In February 1993, some northern stations have outcropped, and those stations represent the depth of either the 8°C or 5°C isotherm. In cases where there is no data, but a station marker exists, the lower isotherm has outcropped as well. By using this plotting technique, we see what may be ITE formations. For example, using the cold thickness/outcropping plots for February and May 1993, the central ITE (~39N 135E) was beginning to subduct in February and became completely subducted by May.

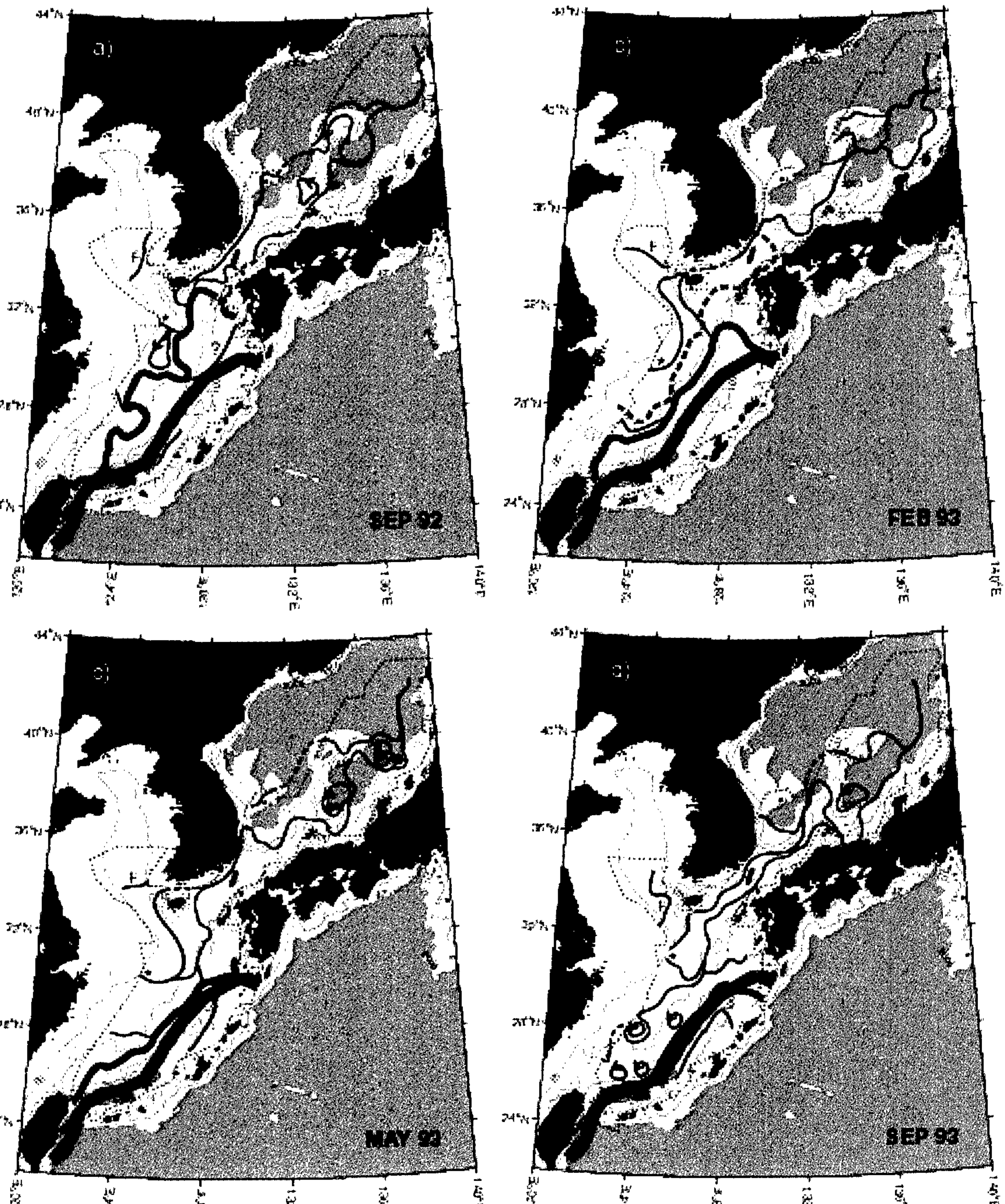

Figure 2. Sixty-meter temperature front structure for a) September 1992, b) February 1993, c) May 1993, and d) September 1993. Fronts have been defined as ~δT>3 °C over 40 km distance (roughly the station spacing). Mean Kuroshio path (taken from Sun and Su, 1994) is shown as a wide gray line. Survey boundaries are drawn as dotted lines. The 100-, 200-, and 1000-meter isobaths are drawn, and bathymetry is shaded every 1000 meters. The red dashed line of b) defines the boundary of the region (to the northeast) where the water column is well-mixed (uniform to within 0.1 °C) to the bottom. Heavy black line in ECS is the eastern temperature front of the Kuroshio.

IMPACT FOR SCIENCE/APPLICATIONS

Our results provide a better description of the water properties and seasonal variability in the upper-ocean circulation of the East China and Japan/East Seas, and its causes. The AXBT data sets have been particularly valuable for understanding the synoptic water mass structure in this region over a very large area, a view usually reserved for remote sensing studies. The intrathermocline eddies described above were heretofore not identified in the extensive AXBT surveys. They may play an important role in the flux of properties across the subpolar front in the Japan Sea. The broad scale AXBT surveys illuminate the difference between surface and sub-mixed layer depth temperature structure, and how this structure evolves seasonally. The two Septembers surveys bring forth the possible difference between sub-mixed layer front structures in the East China Sea, and also how this difference may affect downstream conditions in the Tsushima Strait and southeastern Japan/East Seas. Subsurface synoptic temperature structure aids understanding of previous [e.g., Hickox, et al., 2000] and future remote sensing studies. The large-scale synoptic nature of the surveys provides a context and reference point for future work in these regions.

RELATIONSHIP TO OTHER PROGRAMS

Our work relates particularly to that of Drs. Watts and Wimbush at the University of Rhode Island, who have made new observations of the mesoscale variability in the southern Japan/East Sea. Our work also provides a unique synoptic view of the water mass structure over several seasons to complement other projects in the Departmental Research Initiative in the Japan/East Seas.

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